Inspiratory Muscle Training and Testing: Rationale, Development and Feasibility

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Summary

Background

Inspiratory muscle training (IMT) applies a training stimulus directly to the inspiratory muscles and is distinct from whole-body training. The potential benefits of IMT have yet to be explored in horses.

Objectives

The objectives were: 1) to develop an equine-specific method of testing and training inspiratory muscles; 2) to assess tolerance and feasibility in a pilot study in a commercial Thoroughbred training establishment.

Study Design

Field study

Methods

A mask was used to interface commercial human IMT equipment. Ten horses undertook IMT once daily while stood in the stable approximately 5 days/week over a 9-week period. Inspiratory muscle strength testing (IMST) employed a continuous incremental inspiratory loading protocol alternating two loaded and two minimally loaded breaths until failure to tolerate the load occurred or the maximum 60 breaths were completed. The IMST was undertaken twice; firstly in 10 horses with minimal acclimatisation and secondly in 8 horses experienced with the IMT programme.

Results

The ten horses undertook IMT for a median of 42 days, reaching a median peak training load of 32.5cmH_2O. One horse did not tolerate the mask with repeated snorting and was replaced. All horses completed the IMST. The median peak value in IMST 1 was 27cmH_2O and in IMST 2 was 41cmH_2O. Two of 10 horses reached the maximum possible value in IMST 1; therefore, the test was adapted to permit a higher maximum value, despite this 3/8 horses reached the maximum possible value in IMST 2.

Main limitations

A small number of horses were assessed. The IMST was refined during the study and requires additional refinement.

Conclusion

Inspiratory muscle testing and training were feasible and tolerated in horses. Further research is required to understand whether the IMST values obtained correlate with other physiological/performance outcomes. The potential benefits and/or adverse effects of IMT warrant further investigation.

Introduction

Respiratory muscle training (RMT) applies a training stimulus directly to the respiratory muscles and is distinct from whole body training. The respiratory muscles (upper airway and respiratory pump muscles, including the diaphragm) are skeletal muscles, which are morphologically and functionally like locomotor muscles. Evidence from human and rodent studies indicates that upper airway and respiratory pump muscles can adapt to exercise training[1, 2.] Thus the respiratory muscles appear to be the primary component of the equine respiratory system that may respond to training[3]. The most common form of RMT in humans is inspiratory pressure threshold loading, which involves inhaling against a resistance, which induces adaptations that improve the strength, power and endurance of the inspiratory muscles. This training method is commonly known as inspiratory muscle training (IMT).

Inspiratory muscle training has been used in humans for the management/treatment of a range of medical conditions, including exercise-induced laryngeal obstruction (EILO) and in the treatment of breathlessness for patients with chronic lung and/or heart disease[4]. It has also gained popularity amongst athletes as an ergogenic aid, by improving respiratory muscle performance.

The respiratory musculature of humans has been shown to fatigue during exercise, resulting in complex mechanisms of performance limitation[6]. One of these mechanisms is a respiratory muscle fatigue (RMF) -induced metaboreflex that results in a decrease in blood flow to the exercising limb muscles[7]. The use of IMT in human athletes has been shown to improve athletic performance [4,7,8], by delaying the onset of the RMF and postponing activation of the respiratory muscle metaboreflex. Existence of the respiratory muscle metaboreflex has been confirmed in dogs[9], but it is unknown whether RMF occurs in horses nor whether the respiratory muscle metaboreflex is active during race/competition conditions. As an athletic species the horse is limited by the respiratory system to a greater extent than in most human athletes[10]. However, ventilation in the horse may be facilitated by back flexion and locomotor respiratory coupling thereby reducing the work of the diaphragm in comparison to humans. Despite these differences the respiratory musculature in both maximally exercising humans and ponies commands a similar proportion (~14-20%) of cardiac output[11].

Inspiratory muscle training has been shown to activate the upper airway muscles and has been used to treat EILO in human athletes[4,12]. The high prevalence of upper airway obstructions in racehorses poses significant performance, health and welfare concerns to the Thoroughbred industry. Exercise-induced laryngeal/pharyngeal obstructions can occur when the stabilising muscles of the upper airway are unable to withstand the dramatic increases in airflows and pressures that occur during exercise. Most surgical treatments try to provide a mechanical solution and there is no treatment currently available to improve the strength of the upper airway musculature, thereby providing a functional treatment. If the upper airway muscles in the horse do respond to a training stimulus, this could not only be applied as a non-surgical treatment option, but also as a prophylactic strategy.

In order to set training loads and to monitor improvement, it would be useful to develop methods to measure respiratory muscle performance. Several indices of respiratory muscle function are available in humans, including maximal inspiratory mouth pressures, sniff nasal pressure, oesophageal, gastric and trans-diaphragmatic pressures[13]. Functional outcomes, such as maximal inspiratory muscle shortening velocity, power and endurance, have also been developed. The most common method of assessing respiratory muscle strength is maximal inspiratory pressure (MIP) measured at the mouth during a maximal, volitional inspiratory effort against an occluded airway, which provides a non-invasive index of global inspiratory muscle strength[4]. However, functional testing of the respiratory system in horses is limited by the inability to undertake maximal volitional efforts. Surrogate measures of inspiratory pressure have been described in unconscious or ventilated human patients, including incremental threshold loading and occlusion tests[14,15]. A non-invasive index of inspiratory muscle strength (IMS), not requiring maximal volitional effort, and suitable for routine clinical use in the horse, would benefit the evaluation of the responses of the equine inspiratory muscles to IMT.

Thus, the purpose of this study is to describe an equine-specific method of testing and training inspiratory muscles and the feasibility of implementing this in a pilot study of 10 Thoroughbreds within a commercial training establishment.

Materials and Methods

Equipment:

Equipment for the application of IMT and IMST had previously been developed and undergone preliminary evaluation for use in the horse (unpublished data). Briefly, an airtight mask (Figure 1) made from PETG plastic, covering the entire muzzle, was developed. A tight-fitting latex rubber and Velcro®-fastened head piece secured the mask. An opening at the level of the nares allowed the attachment of IMT pressure threshold valves[a,b] or electronic equipment[c]. The valves[a,b] had been tested in conjunction with the mask using a laboratory based flow/volume simulator pump at flows and volumes commensurate with those measured in resting horses[15]. These tests confirmed the valves created the prescribed inspiratory pressures and did not restrict airflow through flow resistance.

Population:

A convenience sample of 10 healthy Thoroughbred National Hunt racehorses in active training with a single trainer were recruited. All horses were race fit and free from clinical signs of respiratory disease at the start of the study. The study was conducted towards the end of the National Hunt season, from January to March, when the horse's exercise regimens would remain constant during the study period.

Inspiratory Muscle Training (IMT):

Horses were initially introduced to wearing a loose-fitting mask with large air holes for the first session. Gradually, the IMT mask and low load valves[a] (5cmH_2O) were applied by an experienced user. The yard staff were taught how to undertake the daily IMT and given a user guide document; safety aspects were explicitly emphasised and communicated. Subsequently, all IMT sessions were performed by yard staff whilst the horse was standing in its stable. In humans, a wide range of IMT programmes have been used clinically and within research, depending on the patient and outcome of interest. The literature indicates training loads should exceed 30% MIP and typical guidelines in healthy people are to undertake IMT at values of 50-70% MIP or at the maximum that can be sustained for 30 consecutive breaths[4]. In young adults typical MIP values are between 97-128cmH_2O[16].

As the ideal intensity and duration of an IMT programme in horses is unknown, a preliminary training programme was developed in conjunction with an expert in human IMT. The programme was further adapted to promote tolerance, as this was considered key for equine IMT and hence the load is at a lower level with a more gradual increase than programmes used in humans. All horses undertook the IMT programme over a 9-week period, which involved two sessions of 30 'loaded' breaths performed back-to-back with a short break (~2 mins) in-between, completed 5 days/week. The inspiratory load was increased gradually every 4 days (5, 10, 12.5, 15, 20 cmH_2O using one type of valve[a] then in increments of 2.5cmH_2O using the second valve[b]) over the 9-week period, with minor adjustments according to the horse's tolerance to increases in load. The guideline IMT programme was provided for all horses with the ability for users to increase more quickly if the horse was finding the training easy (readily completed both sets of 30 breaths maintaining normal breath duration throughout) and to remain at a level for longer if the user felt the horse was not ready to increase to the next level (unable to complete the 30 breaths, taking short, clipped breaths, or displaying avoidance behaviour such as crossing the jaw). Inspiratory muscle training was not performed for 48 hours prior to racing. The horse's normal exercise and racing schedule continued throughout.

The yard staff were given a daily training diary to complete to log the IMT undertaken and asked to complete a paper questionnaire (anonymously) at the end of the study. Training diaries and yard staff questionnaires were analysed to determine number of training days, acceptance and training level. The trainer was also questioned about subjective interpretation of health and performance of each horse at the start and end of the study.

Inspiratory Muscle Strength Test (IMST):

An electronic inspiratory loading device (POWERbreathe® K5[c]) designed for IMT in human beings was used to implement a continuous incremental pressure loading protocol (Figure 2). The device has been validated in human patients[17] and used to assess changes following IMT[18]. Briefly, the device can measure average load [=pressure] (cmH_2O), breath volume (l), peak flow (l/s), peak power [product of inspiratory load and flow] (W) and work [product of load and volume] (J) continuously at 500Hz, enabling a comprehensive real time analysis of the physical task being undertaken by the inspiratory muscles during loading. Since it is impossible to elicit maximal voluntary efforts from horses, an incremental loading protocol was developed and designed to progressively increase the inspiratory load to the limit of tolerance; the test is analogous to an incremental exercise test. Briefly, two identical loaded breaths were interspersed with two minimally loaded breaths, with the loaded breaths increasing incrementally in magnitude by $2cmH_2O$ each step, to a maximum of 60 breaths in total[c]. By starting the protocol with a low-level loading, the horses had a period of habituation, during which they became accustomed to the unusual sensations of the load, before it became too challenging. The novel introduction of the minimally loaded breaths mitigated the effects of accumulated fatigue and, by permitting full tidal excursions, prevented the development of hypercapnia and lung hyperinflation. The test continued until the horse made an inspiratory effort but was unable to open the valve or all 60 breaths were completed. The index of IMS (IMSi) was the highest load (cmH_2O) at which the horse was able to open the valve. Prior to embarking on this feasibility trial, the IMST had been assessed in 10 horses (7 Thoroughbred, 3 mixed breed) and ages (median age 5 years, range 3-16 years), in which IMS was measured on two separate occasions, in order to assess repeatability. A median value of $21cmH_2O$ and a peak value of $30cmH_2O$ were recorded, with no significant differences in the test re-test values (unpublished data).

The horses underwent 3 days of acclimatisation to the mask before undertaking IMST 1, which had a maximum IMSi of $33cmH_2O$ if the horse completed all 60 breaths[c] (Figure 2). Horses then undertook the IMT programme over a 9-week period, followed by IMST 2, which had a maximum IMSi of $45cmH_2O$ (figure 2). All IMST were undertaken by the same persons who were not blinded to horse identity. The author that lead the IMST was blinded to the progress and the IMT level reached by each horse.

Data Analysis:

The IMSi (cmH_2O), defined as the highest load within the IMST protocol that the horse opened the valve, was considered to be the primary outcome measure of interest for assessing inspiratory strength. However, average load (cmH_2O), breath volume (l), peak flow (l/s), peak power (W) and work (J) were extracted for the paired loaded breaths for IMST 1. Data were assessed graphically and with the use of a Shapiro-Wilk test to determine normality. SPSS (version 24)[c] was used for statistical analysis. Wilcoxon Signed Rank tests were used to compare average load (cmH_2O), breath volume (l), peak flow (l/s), peak power (W) and work (J) for the paired loaded breaths for IMST 1. Significance was set at $P<0.05$.

Results

Ten Thoroughbred horses were recruited initially. One horse was immediately replaced as repeated snorting occurred when the mask was fitted; this horse was diagnosed subsequently with lower airway inflammation. Ten horses completed the IMST 1. A further horse was removed from the yard for unrelated reasons after completing the first test, but before starting IMT, and was replaced with another horse that did not undertake IMST 1. The ten horses that underwent the IMT were all geldings with a median age of 8 years (range 5-10). The number of days of IMT undertaken, the final training level and results of the two IMST are shown in Table 1. The exact number of days of IMT completed by each horse varied slightly according to racing schedule and staff availability. One horse (horse 3) was restricted to box rest for the final three weeks of the IMT period. Two horses were unavailable for the second IMST due to racing commitments. Five of the horses followed the guideline IMT programme exactly, 2 horses were a level ($2.5cmH_2O$) ahead of the suggested programme and three horses a level ($2.5cmH_2O$) behind.

It was necessary to adapt the IMST protocol after IMST 1 because two horses unexpectedly completed the maximum number of breaths possible with the equipment at IMST 1, creating a ceiling effect for IMSi. The IMST 2 had the same number of loaded breaths, same maximum number of breaths, and same increase in load but started at a higher load to allow for a higher end point (figure 2). Despite this, three horses also reached the maximum load of 45cmH_2O in IMST 2. One horse (11) repeatedly crossed his jaw during IMST 2 and failed to take normal breath volumes, thus the validity of this IMSi was questioned. The median peak IMSi value for IMST 1 was 27cmH_2O and for IMST 2 was 41cmH_2O. The median peak training load reached was 32.5cmH_2O thus, at the end of the programme IMT was undertaken at approximately 79% of the IMSi from IMST 2.

The analysis of the loaded breaths in IMST 1 showed that there were no significant differences in load ($p=0.849$), volume ($p=0.135$), flow ($p=0.745$), power ($p=0.170$) or work ($p=0.355$) between first and second of each pair of breaths.

Tolerance for the IMST under the conditions specified was good. Of the 18 tests performed on one occasion a horse repeatedly crossed his jaw which resulted in loss of the air-tight seal; thus, the test result was likely lower than the true value. During IMT, nostril dilation is observed, and thorax movement was clear. Subjectively, horses also appeared to make an obvious inspiratory effort in response to loading. Horse acceptance of IMT was very good, on no occasion were yard staff unable to undertake training due to horse behaviour. The trainer questionnaire did not identify any change in health or performance and no adverse effects were reported by trainers or yard staff.

Discussion

The purpose of this pilot study was to assess the feasibility and tolerance of inspiratory muscle training and testing in the horse. The results show that IMT can be undertaken in a commercial Thoroughbred training establishment. Further research is now required to evaluate whether IMT results in any potential benefits or adverse effects to health and performance.

In both IMST 1 and 2, horses outperformed our expectations from our initial research. As a result, the IMST protocol was changed between the two tests; despite increasing the demands of the IMST 2, horses still reached the test’s upper limit, thus a true IMSi may not have been obtained as horses may have been capable of higher values. The change in protocol, the ceiling effect and lack of control group prevent robust comparisons of the IMST results from tests 1 and 2 but highlight the importance of undertaking a small feasibility trial prior to a larger case control study. Further research will help demonstrate the effect of IMT on IMS and will elucidate whether any increases result from respiratory muscle hypertrophy, improved neuromuscular activation as a result of IMT, or simply an improved ability to tolerate the test.

As horses reached the upper limit of both IMSTs, further adaptation will be required to permit an even higher endpoint. This could be developed through having a higher start point, larger increments between or a decrease in the number of loaded or minimally loaded breaths. As no significant differences were found between breath variables in the first and second loaded breath, we suggest the protocol be amended to one loaded breath. This will permit a higher maximum value, whilst maintaining only small incremental increases and retaining two minimally loaded breaths to maintain tolerance.

During development of the IMST the primary objective was to determine the highest inspiratory load (cmH_2O), the horse was able to open. This was termed the index of inspiratory muscle strength. The equipment used also records additional breath data, such as load (cmH_2O), volume (l), peak flow (l/s), peak power (W) and work (J). In humans, when undertaking a strength test at maximal volitional effort, all these variables typically increase following IMT. For equine testing, further analysis of these variables on an identical test pre and post-IMT will aid understanding of their value. However, it is anticipated that they are of less value in equine testing as it is likely that the horse will do the minimum work required to open the valve, rather than giving a maximum effort, therefore the primary parameter to improve should be the ability to open load i.e. the index of inspiratory muscle strength.

Interestingly the pressures/loads generated by the horse during training and testing were substantially lower than those typically achieved by humans. Although this can be partly explained by inspiratory testing in humans involving a maximal volitional effort, which is not possible in the horse, it is also likely that the scale and anatomy of the equine diaphragm and rib cage alters the relationship between muscle tension and the resultant static pressure. It remains unclear how representative the IMSi is of true maximal inspiratory strength. Research in humans has shown that the values achieved during incremental threshold loading are on average 69% of MIP[14]. The equine training programme was developed to prioritise tolerance; nevertheless, the final IMT level was approximately 79% of our index of IMS. Further research is required to understand whether the IMSi value obtained correlates with other physiological/performance variables.

From an ethical and welfare perspective the application of IMT in horses requires considerable care. The horses were introduced to the mask gradually by the authors, who oversaw the programme. At any point if the horse failed to open the valve during IMT or IMST it was removed. Safety measures were included when the equipment was developed so both the valve and the mask can be rapidly removed in any adverse situation.

In conclusion, this study has shown the novel application of IMT and the development of an innovative method of IMS testing in the horse. Undertaking IMT in the horse is feasible but further research is required to understand any potential benefits or adverse effects.

Manufacturer Addresses

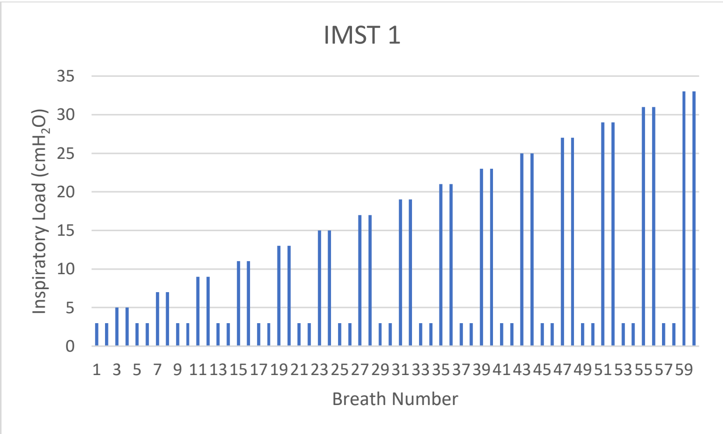
a CPEEP valves, Intersurgical, Wokingham, Berkshire UK

b POWERbreathe® Medic Classic, POWERbreathe International Ltd, Southam, Warwickshire UK

c POWERbreathe K5®, POWERbreathe International Ltd, Southam, Warwickshire UK

d IBM SPSS Statistics for Windows, version 24.0 Armonk, NY:IBM Corp

Figure 1: Equipment for inspiratory muscle training



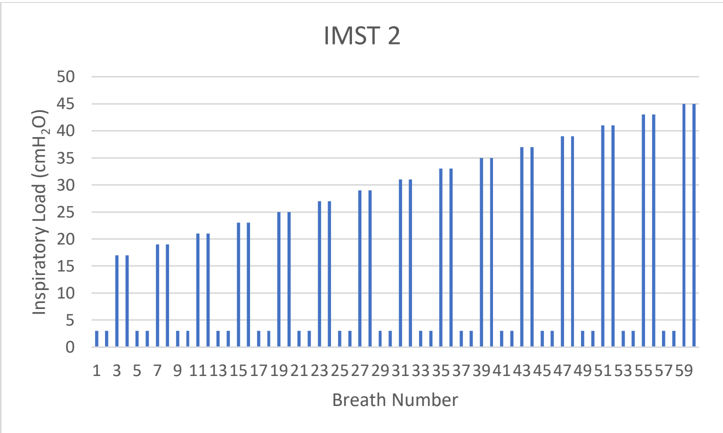


Figure 2: Inspiratory muscle strength test protocols (a) IMST 1 (b) IMST 2. For both tests the maximum number of breaths was 60, of which the maximum number of loaded breaths was 30. The loaded breaths increase by an increment of 2cmH_2O. IMST 2 had a higher start point enabling a higher end point of 45cmH_2O compared to 33cmH_2O in IMST 1.

Horse	IMSi from IMST 1 (cmH_2O)	IMSi from IMST 2 (cmH_2O)	No. Days IMT	Peak training load reached (cmH_2O)
1.	21	35	40	32.5
2.	33*	43	42	35
3.	27	33	44	32.5
4.	21	-	-	-
5.	31	45^	43	32.5
6.	23	-	38	32.5
7.	21	45^	42	32.5
8.	27	-	37	27.5
9.	33*	45^	40	32.5
10.	31	39	44	35
11.	-	27	42	32.5
Median	**27**	**41**	**42**	**32.5**

Table 1 shows the number of days of IMT completed by each horse, the peak training load (cmH_2O), and the IMSi (cmH_2O) from tests 1 and 2. *= horse completed all 60 breaths, 33cmH_2O was the maximum inspiratory load tested. ^= horse completed all 60 breaths, 45cmH_2O was the maximum inspiratory load tested.

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